A REVIEW OF OIL EFFECTS ON MARINE PLANTS

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by

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Abstract

This report presents a brief summary of the literature concerning oil effects on intertidal and subtidal vascular plants and macroscopic algae. The effect and degree of oil contamination on marine plants is determined by characteristics of the oil, environmental variables and plant responses. Each oil spill is unique, therefore there is no simple, predictable response to oil by plants. Marsh plants and algae are able to recover from moderate oil spills, but chronic pollution may completely eliminate some communities.

Oil spills may influence plant communities by mechanical or toxic effects. Toxic effects, from fresh oil, are more complex and subtle than mechanical damage, and may result in long term changes to plant communities due to reproductive and growth abnormalities. Mechanical damage often occurs subtidally as heavy oil sinks and smothers algae. Plant growth may be stimulated at low hydrocarbon concentrations and inhibited at higher concentrations. Marsh communities oiled during active growth are subject to greater damage than at maturity or when they are dormant. Algae tolerate oil contamination more easily than many of their predators, and as a consequence tend to proliferate after oil spills.

Dead plants have shown a very high affinity for oil and can serve to trap oil. Decomposition of oiled plant tissues is slowed, resulting in a decreased supply of detritus to the associated food webs. Incorporation of oil into detritus may influence uptake of hydrocarbons into other trophic levels. A variety of clean-up options are available for marsh and algal communities. Allowing natural recovery to occur has in most cases been the least damaging option for oiled vegetation.

Résumé

Ce rapport présente un bref résumé de la documentation concernant les effets des hydrocarbures sur les plantes vasculaires et les algues macroscopiques intertidales et subtidales. L'effet et l'importance de la contamination des plantes marines par les hydrocarbures sont déterminés par les caractéristiques des hydrocarbures, les variables environnementales et les réactions des plantes. Chaque déversement d'hydrocarbures est unique; et les plantes ne réagissent pas simplement et de façon prévisible. Les plantes et les algues palustres peuvent se remettre d'un déversement moyen, mais la pollution chronique peut éliminer complètement certaines communautés.

Les déversements d'hydrocarbures peuvent influer sur les communautés de plantes par des effets mécaniques ou toxiques. Les effets toxiques d'hydrocarbures frais sont plus complexes et subtils que les dommages mécaniques, et peuvent causer des changements à long terme au niveau des communautés de plantes dus à des anomalies de reproduction et de croissance. Les dommages mécaniques se produisent souvent dans la zone subtidale où les huiles lourdes coulent et étouffent les algues. La croissance des plantes peut être stimulée par de faibles concentrations d'hydrocarbures, mais empêchée par des concentrations élevées. Les communautés de plantes palustres mazoutées durant leur phase de croissance active sont sujettes à des dommages plus importants que lorsqu'elles sont à maturité ou qu'elles sont en repos végétatif. Les algues tolèrent la contamination par les hydrocarbures plus facilement qu'un grand nombre de leurs prédateurs; elles ont donc tendance à proliférer après un déversement d'hydrocarbures.

Les plantes mortes se sont avérées avoir une grande affinité aux hydrocarbures et peuvent servir à les emprisonner. La décomposition des plantes mazoutées est ralentie, réduisant ainsi la quantité de détritus disponible pour les organismes de la chaîne alimentaire associée. L'incorporation d'hydrocarbures aux détritus peut influer sur l'absorption d'hydrocarbures dans d'autres niveaux trophiques. Il existe une variété de mesures de nettoyage pour les communautés d'algues et de plantes des marais. Laisser les plantes se remettre naturellement à la suite d'un déversement a été, dans la plupart des cas, la solution la moins dommageable pour la végétation mazoutée.

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1.0 INTRODUCTION

This review of oil effects on plant communities encompasses those intertidal and subtidal habitats occupied by vascular plants and macroscopic algae. The intertidal habitats are occupied by plants which have become adapted to the unique environmental conditions presented by living in an alternately wet and dry environment. This habitat offers the benefit of fresh nutrients with each tidal cycle for those plants which are able to tolerate the regime. However, the tidal action may also serve to bring in oil (petroleum hydrocarbons) from accidental spills or repeat contamination in a chronically polluted area. Subtidal habitats may afford protection from floating oils but may be the eventual settling area for heavy oil.

Vascular plants which occupy intertidal habitats; grasses, sedges and forbs, are predominantly found on fine sediments where they may form large expanses of gently sloping salt or estuarine marsh. The species mix is quite unique on each of Canada's three coastlines. North Atlantic coastal marshes are floristically similar whether they occur in Europe or North America, and are dominated by the grass, *Spartina alterniflora.* On the Arctic coast, the marsh species are circumpolar in distribution and are dominated by *Puccinellia phryganodes*. The Pacific coast is floristically linked from southern Alaska to northern California; brackish marshes are dominated by the sedge, *Carex lyngbyei,* and salt marshes consist of a variety of species such as *Triglochin maritima, Salicornia virginica, Distichlis spicata* and *Atriplex patula.* Sea-grasses, also vascular plants which have found a sub-tidal niche, consist of very few genera which have a world-wide distribution. The sea-grasses are separated into those which survive in tropical or temperate seas. Eelgrass, (*Zostera marina)* is the main sea-grass found on both the east and west coasts of Canada.

Macroscopic algae are comprised primarily of three divisions: Chlorophyta (green algae), Phaeophtya (brown algae) and Rhodophyta (red algae) (Morris 1971). The reproductive cycles of algae are some of the most complex found in the plant world. For example, the rockweed, *Fucus,* at maturity, produces cavities called conceptacles in the tips of its branches. Within the conceptacles are the male and female reproductive organs. The male organs produce flagellated sperm which are released into the water and which are destined

to find the eggs in their conceptacles. After fusion, a multicellular juvenile is produced which eventually grows into the mature plant. Other algae may have even more complicated reproductive strategies with intermediate filamentous stages, parasitic stages, or with intermediate life forms which produce spores. This report will not enter into details of the various reproductive strategies. It should be noted that all of the reproductive stages may be harmed by oiling. This represents a sensitivity which covers a broader time span and presents more opportunities for disruption than in vascular plants and is often overlooked in evaluating the effects of oil.

Studies conducted in response to large oil spills have revealed various degrees of environmental damage to the flora. Impacts have been assessed as ranging from minimal to extreme. The factors determining the severity and nature of impact include (Straughan 1972a, cited in O'Brien and Dixon 1976):

Oil Effects

- -type of oil
- -viscosity of the oil
- -oil dosage
- -weathering effects
- -prior exposure of the area to oil
- -other stresses in the environment

Biotic Environment

- -plant species
- -age of plants
- -reproductive stage

Physical Environment

- -climate
- -seasonal effects
- -weather
- -delay until spill reaches vegetation
- -wave & current energies
- -physiography of the habitat
- -substrate
- -tidal height

Most assessments of oil impacts on plants have been conducted in response to major accidents. The resulting surveys have in most cases been qualitative; quantitative data relating changes in standing crop of algae and seagrasses to various levels and types of oil contamination are rare. Due to the complexity of factors which need to be considered in

each particular situation, it is difficult to extrapolate from one spill to the next with respect to effects on plants. Very few laboratory studies have been conducted to isolate the different variables, hence there are a number of gaps in our understanding of the effects of oil on various plant communities.

2.0 EFFECTS OF OILS

Crude oil is comprised of three major hydrocarbon classes; alkanes (paraffins), cycloalkanes (naphthenes) and aromatics. Crude oils vary in chemical composition and physical properties. There is general agreement in the literature that the toxicity of oil fractions increases from paraffins, to naphthenes, to aromatics. The most volatile fractions of the crude oil are also the most toxic, therefore the more recent the spill the greater its toxicity. However, in actual fact, compounds in the naptha and kerosene fractions have been identified as the most toxic because those with lower boiling points evaporate rapidly and are unlikely to cause significant damage (Baker 1970). The higher boiling point compounds are made up of larger molecules which may not be able to penetrate plant tissues. Following an oil spill, the aromatic components of petroleum are lost within the initial 24 hours as some of the oil evaporates, some dissolves, and some emulsifies. The solubility of an oil is considered significant in establishing its potential for contributing toxicants to the environment (Nelson-Smith 1973). Many hydrocarbons are broken down by sunlight and this effect appears to be enhanced when the hydrocarbons are bound to plant surfaces.

The environmental persistence of an oil is determined by its physical characteristics. Crude, residual fuel, lubricating oils, tar oils and creosote are among those considered persistent. Non-persistent oils include the distilled oils such as kerosene and gasoline. Persistent oils cause damage by physical action over a long term while non-persistent oils primarily cause damage by their toxicity over a short time span. Non-persistent oils evaporate fairly rapidly while persistent oils weather in characteristic ways. Weathered crude oil decreases in sulphur content, and increases in viscosity and specific gravity. The weathered persistent oils become problems for marine plants as they attach in lumps, weight them down and dislodge them (Van Gelder-Ottway 1975). Light, or less viscous oils are more easily absorbed into the sediment than heavy crude oils, but they are also

reported to dissipate more rapidly (Baker 1970, Hershner & Moore 1977). In addition to the toxicity of these oils, chronic oil pollution may stimulate anaerobic conditions in the substrate and thus may inhibit vascular plant growth (Ranwell 1968, Cowell 1969). Weathering, or the evaporation of volatile hydrocarbons results in a lower toxicity to plants (Baker 1971a). However, mortality of the plants appears to be increased during hot, sunny conditions.

Oil spills may have acute, short-term impacts. Marsh vegetation has been reported to recover from up to three successive moderate size oil spills. However, chronic or severe oil contamination may result in long-term environmental damage (Stebbins 1970, Baker 1971b, Baker 1971e, DeLaune et al. 1979, Hershner & Lake 1980, Krebs & Tanner 1981). The extreme in the range of possible environmental responses was seen in the wreck of the *Tampico Maru*. Spilled diesel oil resulted in both acute and chronic effects. The highly toxic oil was trapped in a cove where recontamination occurred, resulting in a decade of ecological damage (Ganning et al. 1984).

3.0 PHYSICAL ENVIRONMENTAL FACTORS

3.1 Climate, Weather and Seasonal Effects

In general, the colder the climate, the longer it takes for the spilled oil to evaporate or emulsify. In warm water, evaporation takes place rapidly and as a result, toxic effects are less likely to occur in tropical environments. The season during which a vegetation community is oiled affects its eventual chances for recovery. Vegetation oiled in the spring (with Kuwait crude oil) needed the entire summer to recover, while vegetation which was oiled at the end of the growing season recovered well by the same fall (Baker 1971). Transects oiled during the winter did not appear to show detrimental effects the following spring (Baker 1971, Ranwell and Hewett 1964). However, these generalizations do not apply to all oils nor to all species. When sediment or partial plant coverage occurred with No. 2 fuel oil, biomass reductions occurred regardless of the timing of application (Alexander and Webb 1985). Complete coverage of the plant during active growing periods has resulted in a long term reduction in biomass. Sedge plants which overwinter

with new shoots exposed above the sediment were subjected to a jet fuel spill at Vancouver airport in late winter. These plants suffered extensive damage or mortality in response to the application of unweathered jet fuel. Subsequent experimentation showed that mature plants were less susceptible to the effects of the fuel than was the new growth (Moody 1989).

Significant differences have been found between annual and perennial plants. Plants recover by new growth and shed oiled parts. Annual plants are limited in their ability to produce new growth, and are also inhibited in their seed production for the year following oiling. In addition, the oiling of seeds may reduce their viability in the spring (Baker 1971). The seed production of perennials is also reduced when the oiling occurs at the time of flowering. The plants most sensitive to oiling are seedlings of perennials and annuals at all stages of growth (Baker 1971).

3.2 Wave and current energies

Areas with little tidal fluctuation may suffer the greatest impacts from spills. Large tidal fluctuations cause scouring which removes oil from surfaces to which it has adhered. Rocky shores are usually exposed to high energy wave action which helps redistribute deposited oil. In the case of rocky shores or soft bottom habitats there is a potential for oil to be carried to infrequently flooded areas or to be stranded in pools where it can cause significant damage as it remains in situ. In areas where silt deposition it occurring, the oil may be buried and vegetation may colonize the new surface. The stability of such buried oil layers is unknown but may be long-term. If not washed away the oil on the substrate weathers to form a crust and may inhibit plant growth. However, some species such as the reed (*Phragmites*), whose shoots have been reported growing through 10 cm of tarmac, are able to exist despite very difficult circumstances (Haslam 1973 in Baker et al. 1989).

3.3 Substrate

Grain size of substrates appears to be an important factor for the penetration and persistence of oil. Fine textured substrates prevent penetration by oils due the lack of pore space for oil to percolate through. However, once oil is incorporated into fine sediments, it is likely to

remain in situ longer and is likely to promote anoxic conditions. Oxygen is necessary within the sediments for the degradation of oil. As this process occurs, depletion of the oxygen supply can cause anoxic conditions where there is poor water exchange. These anoxic conditions can in turn prolong the residence time of the oil. Recovery of such an area may first require a fresh deposition of sediment over top of the damaged substrates. Depending on the deposition rate, this might take decades (Ganning et al. 1984). Degradation in anoxic environments is considered to be very slow. High levels of petroleum hydrocarbons have been found in sediments after 8 years (Burns & Teal 1971). Oil absorbed by the plants is also unlikely to be degraded. In one case, oil in the sediment was largely degraded after several months, unlike the oil which had penetrated roots and rhizomes of dead *Spartina* and remained unaltered (Hershner and Lake 1980).

In another study it was found that most of the oil entering the marsh ecosystem was incorporated into the anoxic marsh sediments (Burns and Teal 1979). The oil had spread into previously unaffected areas within 2 years. Concentrations of oil were the highest in the surface layers although the oil extended to at least 115 cm in depth (Burns andTeal 1979). Oil penetration has generally been reported to remain within 15 cm of the surface, with the greatest concentrations in the upper 5 cm (Crowell and Lane 1988). Their data also indicate that decomposition of the dead vegetation was delayed by the oil treatment. Dispersant/oil mixes have been demonstrated to penetrate sediments to greater depths than untreated oil (Dorjes 1984 in Farke et al. 1985). However, low concentrations of oil/dispersant mixture applied during a flooding tide or during high water have shown no long-term sediment contamination (Farke et al. 1985, Page et al. 1983).

Chronic oil contamination of marshes may cause greater problems for the stability of marshes than periodic spills. Complete elimination of some marsh communities has been attributed to chronic pollution (Baker 1970, Blumer et al. 1971). Oil contamination may influence the substrate microflora by either decreasing N_2 fixing microflora or may shift the bacterial population to N_2 fixing hydrocarbon-oxidizing species (Coty 1967, Kator & Herwig 1976, Walker & Colwell 1976). If all of the vascular plant cover is destroyed, the contaminated area may revert to an earlier successional stage, dominated by nitrogen-fixing cyanobacteria (Baker 1971a, 1971b).

3.4 Tidal height

The potential for vegetation damage is in part dictated by the the stage of the tide during which hydrocarbons are delivered to the habitat, as well as by subsequent tidal activity. Although oil slicks are delivered to the intertidal habitats by the flooding water, the height of the tide determines how far up the rocky shore, or the plant stems, the oiling will go, whether or not it will be stranded in pools at high elevations and also how quickly it will be scoured from the intertidal environment.

The effects of oil on vascular plants are in part determined by the height of the oil on the plant stems. If the tide levels are such that a portion of the plant escapes oiling, the chances of survival are increased (Baker et al. 1989). A No. 6 oil resulted in death only if the plants were completely covered by oil. If the top third of the plants was unaffected results were not serious. Regeneration was possible if oil was only lightly covering the soil. Successive tidal activity also influenced the plants' abilities to recover (Webb et al. 1981).

4.0 BIOTA

4.1 Response to Oiling

4.1.1 No change

A number of follow-up studies of oil spills have reported no adverse effects on the vegetation. At Cape Hatt, northern Baffin Island, no adverse effects were detected in the biomass, diversity or reproductive condition of submerged macroalgae in response to chemically dispersed oil (Cross et al. 1987). In California, surface kelp blades exposed to the Santa Barbara oil spill were covered by a layer of oil but underneath the blades were healthy (Mitchell et al. 1970). After the Torrey Canyon incident in Britain, eelgrass and the green alga, *Enteromorpha* were found to be unharmed, largely as a consequence of marsh vegetation holding and trapping floating oil (Baker 1975c). Even when adversely affected by oil, in some cases, recovery from damage appears to be rapid once the contamination is stopped. Marsh vegetation has been shown to recover rapidly from light oiling (Baker

1975c). The algae *Ulva, Enteromorpha, Fucus* and *Porphyra* have been reported as colonists of previously heavily contaminated areas (O'Brien and Dixon 1976).

4.1.2 Enhanced growth

Stimulation of algal growth has been reported at concentrations of crude oil up to 700 ppb (Thelin 1981) and at less than 200 ppb for other oils (Steele 1977). Laboratory experiments have shown that algal growth is enhanced at low hydrocarbon concentrations [30-50 ppm] and inhibited at higher concentrations [>50 ppm] (Davenport 1982, Gordon and Prouse (1973) in South and Whittick 1987). On northern Baffin Island, growth stimulation in *Dictyosiphon foeniculaeceus* was suggested to be a response to low levels of oil in sediments (Cross et al. 1987). The vegetative mode of reproduction of the algae at this location meant that the sensitive sexual reproductive stages were not susceptible to oil contamination.

In some cases, algal populations have flourished after fuel spills. After the grounding of the *Tampico Maru* in Baja California, and the *Torrey Canyon* in Britain, benthic algae, especially young *Macrocystis* flourished as a result of removal of algal predators (Bellamy et al., 1967, Nelson-Smith 1968, North 1967). During the recovery period, there is often a successional response where at first there is a lush growth of green algae, followed by brown algae (Nelson-Smith 1968). On northern Baffin Island, the lack of a post-spill enhancement of the subtidal algal community was related to a lack of oil related herbivore mortality (Cross et al. 1987).

Various researchers have indicated that low levels of oil may result in enhanced growth in vascular plants (Mackin 1950, Baker 1969, Baker 1971, Hershner and Moore 1977). The marsh plant *Spartina alterniflora* was found to have undergone an increase in net productivity in response to a No. 6 fuel oil spill (Hershner and Moore 1977). The reasons suggested for oil stimulation include a release of nutrients from the oil or from the vegetation killed by the oil or as a hormonal response to the stress imposed by the oil. Certain species of plants are more tolerant of oiling than are others, as is the case with some domestic plants which are tolerant of weedkillers suspended in a light oil (Baker 1970).

4.1.3 Reduction of photosynthesis

Reduction of photosynthesis has been dealt with in the literature, more from the perspective of algae than from vascular plants. At the individual organism level, exposure to oil depresses algal photosynthesis. There is evidence for accumulation of oil residues in certain plants which may take over a year to dissipate. The concentration of oil required to have an effect on algae depends on the species, age of the plant, age of the oil among other factors. A range of 10-100 ppm of fuel oil in seawater resulted in a 50% reduction of photosynthesis over 4 days (Clendenning and North 1960). For young blades the effect was noted after 3 days of exposure to 1% emulsion of diesel oil (North et al. 1965). The reduction of photosynthesis correlated to the thickness of oil coating the blade (Schramm 1972 in O'Brien and Dixon 1976). Disruption of the cell membranes by some hydrocarbons may also affect photosynthesis (various citations, in O'Brien and Dixon 1976). The reduction in photosynthetic capability appears to be related to oil in solution. Experiments conducted with unicellular green algae have shown that there is a strong relationship between the toxicity of hydrocarbons and their solubility (Hutchinson et al. 1979). In pools covered by an oil, healthy green algae have been observed functioning normally (Nelson-Smith 1968) indicating translucency of the oil and a lack of toxic components in solution.

4.1.4 Absorption of contaminants

Oil may be absorbed in vascular plants through the stomata or directly through the plant membranes as in algae. The viscosity of the oil and the degree to which the plant has been covered by the oil, influences the eventual effect on the plant tissue. Unlike vascular plants, algae lack stomata, which permit relatively large molecules to enter the plant, but toxic oils are able to penetrate algal membranes freely at the point of contact. In vascular plants, once oil has penetrated the plant tissue it is thought to be transported through cellular spaces rather than the vascular system (Dallyn, 1953; Baker 1970). Dead plants have shown a very high affinity for oil (de la Cruz et al. 1981).

4.1.5 Cellular effects

Hydrocarbons have been found to be lipophilic, that is they are attracted to the lipids, or fatty molecules in the cell membranes. This has been suggested as the mechanism for cell membrane disruption and incorporation of hydrocarbons into the cells (Hutchinson et al. 1979). The mucilaginous slime coating of large brown algae has been attributed with preventing damage to the plants.

4.1.6 Exposure

In many cases, the degree of damage to intertidal plants depends on the exposure of the plant at the time of oiling. In oil-covered pools, emergent parts of various algae showed signs of bleaching while the submerged parts were healthy (O'Brien and Dixon 1976). Observations following the Santa Barbara spill noted the greatest damage occurring in the high intertidal where the oil was stranded for long periods of time. In mid-tidal areas, where oil was scoured and removed, recolonization was rapid indicating much less damage.

Investigations following the *Amoco Cadiz* spill in France revealed that mortality of seaweeds was related to the length of exposure to the oil. High intertidal plants were most severely affected (Floc'h and Diouris 1981 in South and Whittick 1987). After fourteen months, oil residues were still being detected in the rockweeds but growth rates had returned to normal (Topinka and Tucker 1981 in South and Whittick 1987). Several studies have reported recovery approximately one year after the original oiling (Chan 1972, Stebbings 1968, Bellamy et al. 1967).

4.1.7 Mechanical effects

If the spilled oil has time to weather and loose its lower boiling point toxic components prior to reaching shore, the damage to plants is primarily mechanical with major effects arising from smothering (Baker 1970, Nelson-Smith 1973). Intertidal fucoids have been smothered and subject to physical breakage by wave action as a result of heavy oil deposition (Nelson-Smith 1973). Some oil coated algal blades are known to recover. For those algae which re-grow annually from their basal structures, the loss of some of their

blades to oil may be compared to the effects of a winter storm (Nelson-Smith 1973). However, if these losses occur during the growing season, the productive and reproductive capacity of the plant may be diminished. The deposition of oil on the sediments may inhibit the settling of spores and consequently the reproductive success of the plant (Straughan 1971).

Oiled sediments appear to inhibit the growth of new rhizomes. Plants growing in oiled substrates in Brittany, were all vertical and had no side branching. A similar response was noted in *Spartina alterniflora* transplanted to oily substrates. The transplants survived but very few new shoots emerged. (Krebs & Tanner 1981).

4.1.8 Reproductive and structural deformities

Certain toxic components of oils have been reported to cause growth abnormalities in affected plants and may inhibit synthesis of nucleic acids (which are important for protein synthesis and reproduction) The effects on nucleic acids may be important in understanding how certain plants are able to develop resistant varieties. Plants which survived after being subjected to the toxic effects of jet fuel, displayed altered reproductive capacity and structural deformities in growth the year in which the spill occurred (Moody 1989). Crude oils and dispersant treated vegetation on the Atlantic seaboard also displayed leaf and stem deformities in the first year but these were no longer detectable in the second year (Crowell & Lane 1988).

4.1.9 Chronic effects

A variety of researchers have indicated that the diversity of organisms may be reduced in areas of chronic oil pollution. The contaminating oil may in such environments function as a selecting agent for tolerant species. Once the contamination has ceased, the stressed organisms have shown improvements in quality and abundance (Perkins 1968 in O'Brien & Dixon). It has been suggested that plants found growing on sediments containing naturally high hydrocarbon levels may have become environmentally adapted to the contaminated conditions. *Puccinellia maritima* from a hydrocarbon rich environment showed greater tolerance of water contaminated by hydrocarbons than did those plants from low hydrocarbon environments (Amakiri in Baker et al. 1989). Examination of the

intertidal plants in an area of natural submarine oil seepage in southern California has revealed that chronic exposure promotes the persistence of tolerant species (Straughan 1972).

4.2 Species Specific Response

4.2.1 Algae

Observers have found that in many cases it has been difficult to detect harmful effects on large algae, particularly as leaves are shed during certain seasons. The more delicate algae such as sea-lettuce (*Ulva*), and red algae show response to oil by loss of colour or turgor. After the wreck of the *Tampico Maru*, the spilt diesel oil had dramatic effects on shoreline flora and fauna. Below the intertidal zone, kelp growth increased dramatically in response to the loss of the grazing community (sea-urchins and abalone). This heavy growth continued for three years after the spill (Nelson-Smith 1968). The large brown kelps appear to be relatively unaffected by oil spills, but they have been severely damaged by detergent application and have also reportedly been affected by fresh fuel oil (Clark et al. in O'Brien and Dixon 1976). Other species of algae showed severe effects in areas of the plant such as the basal area of the stipe where oil could be trapped (O'Brien and Dixon 1976).

Algae in general, are able to tolerate oil contamination more easily than many of their predators, which has resulted in proliferation of algae after oil spills. From a community level, although individual species may recover well following an oil spill the community structure may experience long-term alterations. After the *Tampico Maru* spill, 90% of the biota was restored in 3-4 years (Mitchell et al. 1970). However, even after 14 years, the affected cove had not recovered its pre-spill diversity (O'Brien & Dixon 1976).

Many upper intertidal algae, especially species of the red (Rhodophyta) and brown (Phaeophyta) algae tend to attract oil as their surfaces dry. The adhering oil creates gas-exchange problems and causes mechanical damage such as breakage or loss of leaves. Red algae appear to be the most sensitive to toxic effects of oil. Green algae are next in sensitivity to the reds, but in general, show a dramatic recovery after the immediate effects

of an oil spill; predominantly as a result of removal of grazing pressure (O'Brien and Dixon 1976).

The seasonal life histories and the varying sensitivity of different life history stages of intertidal algae affect their susceptibility to oils and detergents contamination (Boney 1968). A few studies have shown that even at very low concentrations of oil in water, the fertilization of rockweed (*Fucus*) can be affected (Johnston 1977, Steele 1977, Derenbach and Gereck 1980). The protracted fruiting period of rockweeds in part compensates for the reproductive sensitivity (O'Brien and Dixon 1976) but does not compensate in a chronically contaminated environment. The reproductive sensitivity may may reflect on the recovery potential for species in isolated locations.

In general it may be stated that it is very difficult to assess the effects of oil on algae, because it has been impossible to isolate the effects of oil from other environmental contaminants and from natural variability (O'Brien and Dixon 1976). Subtidal algae appear to suffer primarily mechanical damage and are smothered by heavy sinking oil, while intertidal algae are more sensitive as they respond both to toxic and mechanical effects. The effects of oil on the algae appear to be largely transitory with recolonization of affected areas occurring quite rapidly once physical conditions have stabilized.

4.2.2 Vascular Plants

Most of the marsh/oil studies have indicated that annuals fare more poorly than do perennials in an oiled environment. Annuals have small root systems and low food reserves, thus making recovery from oil pollution difficult. However, annuals tend to be the first plants which recolonize oiled habitats. Neither oiled substrates nor dead oiled plants prevented the growth of annual seedlings (Dicks 1975). In one study, the annuals actually increased in biomass in areas where cordgrass had been killed by oil, although they did not establish until the year after oil application. This was attributed to seed inhibition due to oil effects or a scarcity of seed following the cordgrass mortality (Crowell and Lane 1988).

Perennials with large rhizomes (underground stems) are thought to tolerate oiling since new growth is able to regenerate from below-ground even after the aerial parts have been destroyed (Baker 1970). However, the growth of roots and rhizomes may be reduced by the incorporation of oil into the substratum (Krebs & Tanner 1981). Dead plants showed a very high affinity for oil and decomposition of the plant tissues in some cases has been reduced by more than 50 percent as a result of oiling (de la Cruz et al. 1981). Fleshy leafed plants such as *Batis maritima*, and *Salicornia* spp. are particularly sensitive to oil coating their leaves, stems or substrate (Dicks 1975, Chan 1977).

Cordgrass (*Spartina*), the predominant marsh genus in the temperate Atlantic coast environments, appears to be a fairly tolerant genus in terms of oil pollution, both chronic and acute. It has been reported that *S. anglica* contains 80% of its production underground (Baker 1971). *Spartina anglica* has been reported to be able to recover from one or two oilings (Baker et al. 1989). *Phragmites*, a reed which occurs on both the east and west coast of Canada, has been demonstrated to survive 10 oilings (Baker et al. 1989). In a waterlogged environment, *Phragmites* was able to survive, in a stunted state, in 57% heavily weathered oil. It exhibited good growth at 20% oil concentration and at 3%, the shoot length was reduced but otherwise growth was similar to that of non-oiled conditions (Baker et al. 1989).

Where sediment hydrocarbon levels were below 2,000 µg/g [as a result of a No. 6 fuel-oil spill] *Spartina alterniflora* was not affected or showed a slight enchancement of growth. Above this level of contamination, production diminished with an increasing concentration of hydrocarbons. Flowering was stimulated. Where hydrocarbon concentrations exceeded 10,000 µg/g, below-ground organs were killed and regrowth was patchy (Krebs & Tanner 1981). Therefore although a fuel oil may have relatively low toxicity, at high levels, the lethal and sublethal effects can lead to rhizome mortality, and consequently in high energy environments to shoreline erosion.

Seagrasses function as a natural absorbent for oil. Seagrass detritus retains oil and is accumulated in the upper intertidal zone. Decomposition of oiled seagrasses is substantially slower than for clean seagrass detritus, thereby reducing the input of detritus into the food web (Chan 1977). A few studies have reported significant mortalities and slow recovery

for seagrasses affected by spills of diesel or crude oil but in general very little attention has been paid to the effects of oil spills on sea-grasses. As sea-grasses occur subtidally any effects are likely not from acute toxic effects of oil but from heavy oil which may sink and smother the plants. An exception to this condition would be seagrasses which occupy shallow intertidal habitats, where their floating leaves could easily be coated by oil. Such incidents have not been recorded in the literature.

5.0 CLEAN-UP AND RECOVERY

Restoration has been defined as "the return of the ecosystem to within limits of natural variability by natural and/or artificial means. It is important to realize that natural variability occurs through time and space due to ecological interactions as well as seasonal, annual, and long-term climatic and oceanographic changes" (Ganning et al. 1984). Other definitions for recovery range from; restoration of the environment to general ecological usefulness; to, restoration to original structure and function with the original species complement. It is likely that given time all disturbed environments will regain some ecological usefulness; however, the degree of damage dictates how close one can come to the original community structure.

Recovery and restoration of damaged habitats can be interpreted at many levels. In order of increasing difficulty and likelihood of occurrence, these are:

- restoration of environment to usefulness as perceived by the general public
- restoration to original structure and function but with altered species composition
- restoration to original structure and function with original species composition

Various measures have been employed to eliminate or mitigate damage to natural habitats. Chemical coutermeasures are complex and continually evolving, as a result, only mechanical clean-up measures are dealt with in this report.

Removal of free floating oil is important in order to reduce further oil damage. A variety of techniques have been employed involving various types of skimming or suctioning equipment. Damage to plant communities is only avoided when the mechanical effects of the clean-up activity do not impinge on the habitat, for example when equipment or manual labour do not trample vegetation or mix oil further into soft sediments.

Cutting of oiled vegetation has produced varying results depending on the season of cutting. Cutting during spring and fall has resulted in decreased growth the following year. Winter cutting appears to have little effect on future growth, provided that the rhizomes were not harmed (Baker et al. 1989). In some cases clean-up efforts have created more problems than they have solved. In one situation, the manual of cutting of lightly oiled reeds, and high pressure washing of the marsh surface resulted in the destruction of the rhizomes of the plants and incorporated substantial amounts of water and oil directly into the substrate. After the original oiling the plants were only lightly coated and could have been expected to recover whereas the clean-up operation endangered the recovery potential of the marsh. The $750,000 clean-up was thought to have caused significantly more damage than the initial oiling (Owens and Foget in Baker et al. 1989). Similarly, shoreline clean-up efforts after the Valdez oil spill which used high pressure and hot water spraying were reported to have caused significant damage to the vegetation communities (P. Gabrielson pers. comm.).

Spring or fall burning of oil soaked vegetation was found to have minimal effects on the growth of cordgrass, while winter burning was likely to be the least damaging (Baker et al. 1989). This may not be as successful with the sedge *Carex lyngbyei* due to its habit of overwintering with shoots which protrude above the sediment. Other studies have found that burning the vegetation had a significantly more detrimental effect than cutting (McCauley & Harrel 1981). Allowing natural recovery to occur has usually been the least damaging option for marsh environments.

Stripping or heavily contaminated substrates and replacing them with clean soil may be an option in severely damaged situations where sediments are heavily contaminated. This operation must be followed by rehabilitation of the vegetation which in most cases would be done by transplanting.

6.0 SUMMARY

The effect and degree of oil contamination on marine plants is determined by characteristics of the oil, environmental variables and plant responses. Each oil spill is unique, therefore there is no simple, predictable response to oil by plants. However, a general summary, indicating the various responses between the plant groups is presented in Table 1.

Marsh plants and algae are able to recover from moderate oil spills. However, chronic or severe oil contamination has resulted in long-term environmental damage. Fresh oil is the most damaging to vegetation due to its toxic components. Weathering results in a lower toxicity to plants and the resulting damage to plants is primarily mechanical with major effects arising from smothering. Toxic effects occur primarily in intertidal vegetation whereas mechanical damage may occur both intertidally and subtidally. Mechanical damage is usually restricted to individuals or portions of communities. Toxic effects are more complex and subtle than mechanical damage, and may result in long term changes to plant communities due to reproductive and growth abnormalities or by the development of pollution resistant strains of plants in chronically contaminated areas.

In general it has been difficult to evaluate the effects of oil on algae, because it is impossible to isolate the effects of oil from other environmental contaminants and from natural variability. Algal growth is stimulated at low hydrocarbon concentrations and inhibited at higher concentrations. The concentration of oil required to have a detrimental effect on algae depends on the species, age of the plant, and age of the oil, among other factors. Algae in general, are able to tolerate oil contamination more easily than many of their predators, which has resulted in the proliferation of specific groups of algae after oil spills. In order of decreasing sensitivity to oil spills the major algal groups are: red algae, green algae, and brown algae. Most brown algae (including kelp) are protected by a mucilaginous coating which has been attributed with preventing damage to the plants. The effects of oil on the algae appear to be largely transitory with colonization of affected areas occurring quite rapidly once physical conditions have stabilized. Despite the rapid recolonization which takes place, the original communities may not be duplicated and diversity may be reduced, particularly in areas subject to chronic contamination.

TABLE 1: EFFECTS OF PETROLEUM HYDROCARBONS ON MARINE PLANTS

EFFECT	BENTHIC ALGAE	INTERTIDAL ALGAE	SEAGRASSES	MARSH PLANTS
mortality	Infrequently reported No data on lethal conc.	Suffocation, Toxic effects Dependent on extent and duration of oil coverage	May be significant Recovery slow Poorly documented	Suffocation, Toxic effects Damage depends on growth stage Long-term effects due to oil accumulation in sediment, which affects underground storage organs
physical damage	Due to weight of oil, Prevented in brown algae by mucilaginous secretions	Due to weight of oil Prevented in brown algae by mucilaginous secretions	Not documented	Due to weight of oil
photosynthesis	Reduced during exposure,	Stimulated or depressed depends on species; extent and duration of exposure	Not documented	Degree varies with type of oil
growth & reproduction	No effects reported from oil in water or sediments Young plants and repr. stages most sensitive Effects less severe during low growth periods	Reduced reproduction & colonization in browns. Effects less severe during low growth periods	Effects are expected to be similar to marsh plants	Reduced growth and reproduction Increased seed & flower production Annuals more sensitive than perennials Slow recovery & reduced growth if oil incorporated into sediment
uptake	Directly via algal membrane	Directly via algal membrane	Likely, via stomata or directly at point of contact	Via stomata or directly at point of contact Hydrocarbons transported via cellular spaces
physiology	Red. RNA, DNA synthesis, Accumulation of metabolic end products, Disrup. chloroplast membr.	Red. gas diffusion rates Accumulation of metabolic end products, Reduced CO_2 exchange	Not documented	Synthesis of nucleic acids inhibited Reduced CO_2 exchange
habitat loss	Due to oil accumulations	Determined by persistence of oil & energy environment	Determined by persistence of oil , energy environment, and oil levels in sediment	Determined by persistence of oil , energy environment, and oil levels in sediment
indirect effects	Enhanced growth due to due to changes in fauna elimination of grazers or tolerance of hydrocarbons	Green algal blooms, due to elimination of grazers	Decomposition inhibited by oiling, implications to food webs	Long-term community changes in response to tolerant or sensitive species
mechanical clean-up	Not documented	High pressure or hot water washing - very damaging	Not documented	Physical disruption can be severe. Cutting appears to be least disruptive.
vulnerability	Species with floating fronds susceptible to oil slicks Accumulations of oil in benthic environments could lead to smothering of algae and habitat disruption	Varies according to species, location, type & volume of oil, season, persistence, and clean-up activities. Red algae most sensitive.	Depending on location could be extremely sensitive.	Varies according to species, location, type & volume of oil, season, persistence, and clean-up activities.

The potential for damage to marshes is in part dictated by the the stage of the tide during which oil delivered to the habitat, and also by subsequent tidal activity. The effects of oil on vascular plants are influenced by the height of the oil on the plant stems; the more completely covered by oil the plant is, the more severe the effects. Most of the oil entering the marsh ecosystem is incorporated into the marsh sediments and may spread to previously uncontaminated areas through the sediments. The oil itself is likely to cause anoxic conditions in fine sediments, and as oxygen is necessary for the degradation of the oil, the oil may remain in the sediments, unaltered, for a number of years. This has not been found to cause problems for the colonization of annual species, but may prevent perennial plants from developing or growing normally.

The season during which a vegetation community is oiled affects its eventual chances for recovery. Communities which are oiled during winter show the least damage, whereas those oiled during active growth are subject to the greatest damage. Mature plants are less sensitive than new growth. The plants most sensitive to oiling are seedlings of perennials, and annuals at all stages of growth. Annuals, tend to be the first plants which recolonize oiled habitats. Fleshy leafed plants are particularly sensitive to oil coating their leaves, stems or substrate. Seagrasses, in general, have been the least investigated marine plant communities with respect to oil contamination.

Dead plants have shown a very high affinity for oil and function as a natural absorbent for oil. The detritus retains oil and accumulates in the upper intertidal zone. Decomposition of oiled plant tissues in some cases has been reduced by more than 50 percent resulting in a decreased supply of detritus to the associated food webs. Incorporation of oil into detritus may also influence uptake of hydrocarbons into other trophic levels.

Oil may be absorbed in vascular plants through the stomata or directly through the leaf. In vascular plants, once oil has penetrated the plant tissue it is thought to be transported throughout the plant in its cellular spaces. Certain toxic components of oils have been reported to cause growth and reproductive abnormalities in affected plants.

The diveristy of organisms may be reduced in areas of chronic oil pollution. Chronic oil pollution may stimulate anaerobic conditions in the substrate and may inhibit vascular plant growth. Complete elimination of some marsh communities has been attributed to chronic pollution.

Obvious oil contamination of habitats often results in pressure for clean-up action, however, from the perspective of the plant communities this may cause more damage than the initial oiling. Allowing natural recovery to occur has in most cases been the least damaging option for oiled vegetation.

7.0 BIBLIOGRAPHY

1. Alexander, M. A., Patricia Longabucco, and David M. Philips 1981. The Impact of Oil on Marsh Communities in the St. Lawrence River. pp. 333-340 **Proc. 1981 Oil Spill Conf.** American Petroleum Institute, Washington, D.C.

2. Alexander, Steve K. and James W. Webb, Jr. 1985. Seasonal Response of *Spartina alterniflora* to Oil. **Proc 1985 Oil Spill Conf.** American Petroleum Institute, Washington, D.C.

3. Arthur, D.R. 1968. The Biological Problem of Littoral Pollution by Oil and Emulsifiers -- A Summing Up. pp159-164. In: Carthy, J.D. and D.R. Arthur (eds) 1968. **The Biological Effects of Oil Pollution on Littoral Communities.** Proc. of a Symposium held at the Orielton Field Centre, Pembroke Wales on 17-19 Feb 1968.

4. Baca, Bart J. and Charles D. Getter. 1985. Freshwater Oil Spill Considerations: Protection and Cleanup. pp. 385-390. **Proc. 1985 Oil Spill Conf.** American Petroleum Institute, Washington, D.C.

5. Baker, J. M. 1969. The Effects of Oil Pollution on Salt Marsh Communities. In Field Studies Council Oil Pollution Research Unit, Annual Report for 1968. Section B, pp 1-10.

6. Baker, J. M. 1970. The Effects of Oil on Plants. **Environ. Pollut.** 1:27-44.

7. Baker, J.M. 1971a. Comparative toxicities of oils, oil fractions and emulsifiers. In Cowell, E.B. (ed.) **The Ecological Effects of Oil Pollution on Littoral Communities.** Proc. Symp., Institite of Petroleum, London, pp78-87.

8. Baker, J.M. 1971b. Seasonal effects of oil pollution on salt marsh vegetation. **Oikos 22**: 106-110

9. Baker, J.M. 1971c. Growth stimulation following oil pollution. In: Cowell, E.B. (ed.) **The Ecological Effects of Oil Pollution on Littoral Communities.** Proc. Symp., Institite of Petroleum, London, pp72-77.

10. Baker, J.M. 1971d. Effects of cleaning. In: Cowell, E.B. (ed.) **The Ecological Effects of Oil Pollution on Littoral Communities.** Proc. Symp., Institite of Petroleum, London, pp72-77.

11. Baker, J.M. 1971e. The effects of oils on plant physiology. In: Cowell, E.B. (ed.) **The Ecological Effects of Oil Pollution on Littoral Communities.** Proc. Symp., Institite of Petroleum, London, pp72-77.

12. Baker, J.M. 1975a. Biological Monitoring -- Principles, Methods and Difficulties. pp 41-53. In: Baker, J.M. (ed.) 1975. **Marine Ecology and Oil Pollution.** John Wiley & Sons, Toronto.

13. Baker, J.M. 1975b. Ecological Changes in Milford Haven During its History as an Oil Port. pp55-66. In: Baker, J.M. (ed.) 1975. **Marine Ecology and Oil Pollution.** John Wiley & Sons, Toronto.

14. Baker, J.M. 1975c. Investigation of Refinery Effluent Effects Through Field Surveys. pp201-225. In: Baker, J.M. (ed.) 1975. **Marine Ecology and Oil Pollution.** John Wiley & Sons, Toronto.

15. Baker, J.M., J.A. Bayley, S.E. Howells, J. Oldham, and M. Wilson. 1989. Oil in Wetlands. pp37-59. In: Dicks, B. (ed.) 1989. **Ecological Impacts of the Oil Industry.** John Wiley & Sons, Toronto.

16. Bellamy, D.J. and A. Whittick. 1968. Problems in the Assessnt of the Effects of Pollution on Inshore Marine Ecosytems Dominaed by Attached Macrophytes. pp 49-54. In: Carthy, J.D. and D.R. Arthur (eds) 1968. **The Biological Effects of Oil Pollution on Littoral Communities.** Proc. of a Symposium held at the Orielton Field Centre, Pembroke Wales on 17-19 Feb 1968.

17. Bellamy, D.J, P.H. Clarke, D.M. John, D. Jones, A. Whittick and T. Darke. 1967. Effects of pollution from the *Torrey Canyon* on littoral and sublittoral ecosystems. **Nature** 216:1170-1173.

18. Boney, A.D. 1968. Experiments with some Detergents and Certain Intertidal Algae. pp55-71. In: Carthy, J.D. and D.R. Arthur (eds) 1968. **The Biological Effects of Oil Pollution on Littoral Communities.** Proc. of a Symposium held at the Orielton Field Centre, Pembroke Wales on 17-19 Feb 1968.

19. Bott, T.L., K. Rogenmuser and P. Thorne. 1976. Effect of No.2 Fuel Oil, Nigerian Crude Oil and Used Crankase Oil on the Metabolism of Benthic Algal Communities. In: **Sources, Effects and Sinks of Hydrocarbons in the Aquatic Environment.** Proc. of the Symposium American University Washington D.C. 9-11 August 1976. AIBS

20. Brunnock, J.V., D.F. Duckworth, and G.G. Stephens. 1968. In **Scientific Apects of Pollution of the Sea by Oil.** Institute of Petroleum, London, pp. 12-27

21. Burns, K.A. and J.M. Teal. 1971. The West Falmouth Oil Spill: Hydrocarbons in the Salt Marsh Ecosystem. **Estuarine and Coastal Marine Science** 8, 349-360.

22. Chan, Elaine I. 1977. Oil Pollution and Tropical Litttoral Communities: Biological Effects of the 1975 Florida Keys Oil Spill. pp. 539-545. **Proc. 1977 Oil Spill Conf.** American Petroleum Institute, Washington, D.C.

23. Clendenning, K.A. and W.J. North. 1960 The effects of waste discharge on kelp: phenol and cresols. **Univ. Calif. Inst. Mar. Resources, 60(4),** 45-47.

24. Conan, G. 1982. The long-term effects of the *Amoco Cadiz* oil spill. **Philosophical Transactions of the Royal Society of London(B) 297**:323-333.

25. Coty, V.F. 1967. Atmospheric nitrogen fixation by hydrocarbon-oxidizing bacteria. Biotechnol. Bioeng. 9:25-32.

26. Cowell, E.B. 1969. The effects of oil pollution on salt marsh communities in Pembrokeshire and Cornwall. **J. Appl. Ecol. 6:133-42.**

27. Cowell, E.B. (ed.) 1971. **The Ecological Effects of Oil Pollution on Littoral Communities.** Proc. Symp., Institite of Petroleum, London, pp78-87.

28. Cross, W.E., R.T. Wilce and M.F. Fabijan Effects of Experimental Releases of Oil and Dispersed Oil on Arctic Nearshore Macrobenthos. III. Macroalgae **Arctic (40)** SUPP. 1 (1987):211-219.

29. Crowell, M.J. and P.A. Lane. 1988. The Effects of Crude Oil and the Dispersant Corexit 9527 on the Vegetation of a Nova Scotian Saltmarsh: Impacts After Two Growing Seasons. Unpublished Report EE-103. Prepared for Environment Canada Environmental Protection Directorate, Ottawa

30. Dalby, D.H. 1968. Some Factors Controlling Plant Growth in the Intertidal Environment. pp31-37. In: Carthy, J.D. and D.R. Arthur (eds) 1968. **The Biological Effects of Oil Pollution on Littoral Communities.** Proc. of a Symposium held at the Orielton Field Centre, Pembroke Wales on 17-19 Feb 1968.

31. Dallyn, S. 1953. Herbicidal action of oils. **Cornell Univ. Agr. Exp. Sta. Memoir**, Ithaca, New York, 316.

32. Davies, J.A. and D.E. Hughes. 1968. The Biochemistry and Microbiology of Crude Oil Degradation. pp 139-144. In: Carthy, J.D. and D.R. Arthur (eds) 1968. **The Biological Effects of Oil Pollution on Littoral Communities.** Proc. of a Symposium held at the Orielton Field Centre, Pembroke Wales on 17-19 Feb 1968.

33. de La Cruz, A.A., C.T. Hackney and B. Rajanna. 1981. Some effects of crude oil on a *Juncus* tidal marsh. **Journal of the Elisha Mitchell Scientific Society. 97(1)**:14-28.

34. DeLaune, R.D., C.J. Smith, W.H. Patrick, J.W. Fleeger and M.D. Tolley. 1984. Effect of oil on a salt marsh biota: Methods for restoration. **Environ. Pollution., Ser. A., 36**:207-227.

35. Delaune, R.D., W.H. Patrick Jr. and R.J. Buresh. 1979. Effect of crude oil on a Louisiana *Spartina alterniflora* salt marsh. **Environ. Pollut. 20**:21-31.

36. Derenbach, J.B. and M.V. Gereck. 1980. Interference of petroleum hydrocarbons with the sex pheromone reactions of *Fucus vesiculosus* (L). **Journal of Experimental Marine Biology and Ecology 44**:61-65.

37. Dicks, B and K. Iball. 1981. Ten Years of Saltmarsh Monitoring -- The Case History of a Southampton Water Saltmarsh and a Changing Refinery Effluent Discharge. pp. 361-373. **Proc. 1981 Oil Spill Conf.** American Petroleum Institute, Washington, D.C.

38. Dicks, B. 1975. The Effects of Refinery Effluents: The Case History of a Saltmarsh. pp227-245. In: Baker, J.M. (ed.) 1975. **Marine Ecology and Oil Pollution.** John Wiley & Sons, Toronto.

39. Dicks, B. and R. Wright. 1989. Coastal Sensitivity Mapping for Oil Spills. pp235-259. In: Dicks, B. (ed.) 1989. **Ecological Impacts of the Oil Industry.** John Wiley & Sons, Toronto.

40. Duval, W.S. (ed.) 1985. A review of the biological fate and effects of oil in cold marine environments. Unpubl. Rep. by ESL Environmental Sciences Limited,

S.L. Ross Environmental Research Limited and Arctic Laboratories Ltd. for Environment Canada, Environmental Protection Service, Edmonton. 242 pp.

41. Farke, Hubert and Dietrich Blome. 1985. Field Experiments with Dispersed Oil and a Dispersant in an Intertidal Ecosystem: Fate and Biological Effects. pp. 515-520. **Proc. 1985 Oil Spill Conf.** American Petroleum Institute, Washington, D.C.

42. Ferrell, Ronald E., Ernest D. Seneca, and Rick A Linthurst. 1984. The Effects of Crude Oil on the Growth of *Spartina alterniflora* Loisel. and *Spartina cynosuroides* (L.) Roth. **J. Exp. Mar. Biol. Ecol. 83**:27-39.

43. Floc'h, J.-Y., and M. Diouris. 1980. Initial effects of *Amoco Cadiz* oil on intertidal algae. **Ambio 9**:284-286.

44. Ganning, B., D.J. Reish, and D. Straughan. 1984. Recovery and Restoration of Rocky Shores, Sandy Beaches, Tidal Flats, and Shallow Subtidal Bottoms Impacted by Oil Spills. pp7-36 In: Cairns, J.Jr. and A.L. Buikema Jr. (eds.)1984. **Restoration of Habitats Impacted by Oil Spills.** Butterworth Publishers. Toronto.

45. Goldacre, R.J. 1968. Effect of Detergents and Oils on the Cell Membrane. pp131-137. In: Carthy, J.D. and D.R. Arthur (eds) 1968. **The Biological Effects of Oil Pollution on Littoral Communities.** Proc. of a Symposium held at the Orielton Field Centre, Pembroke Wales on 17-19 Feb 1968.

46. Harper, J.R. and B. Humphrey. 1985. **Stranded Oil in Coastal Sediments: Permeation in Tidal Flats.** Environmental Studies Revolving Funds Report 031. Ottawa. 24 p.

47. Hershner, C. and J. Lake. 1980. Effects of Chronic Oil Pollution on a Salt-Marsh Grass Community. **Marine Biology 56**:163-173.

48. Hershner, C. and Kenneth Moore. 1977. Effects of the Chesapeake Bay Oil Spill on Salt Marshes of the Lower Bay. pp.529-533. **Proc. 1977 Oil Spill Conf.** American Petroleum Institute, Washington, D.C.

49. Hoi-Chaw, Lai and Feng Meow-Chan. 1985. Field and Laboratory Studies on the Toxicities of Oils to Mangroves. pp. 539-546. **Proc. 1985 Oil Spill Conf.** American Petroleum Institute, Washington, D.C.

50. Hsiao, S.C., D.W. Kittle and M.G. Foy. 1978. Effects of crude oil and the oil dispersant Corexit on primary production of arctic marine phytoplankton and seaweed. **Environmental Pollution 15**:209-221.

51. Hutchinson, Thomas C., Johan A. Hellebust, Donald Mackay, Deborah Tam, and Peter Kauss. 1979. Relationship of Hydrocarbon Solubility to Toxicity in Algae and Cellular Membrane Effects. pp. 541-547. **Proc. 1979 Oil Spill Conf.** American Petroleum Institute, Washington, D.C.

52. Johnston, C.S. 1977. The sub-lethal effects of water-soluble extracts of crude oil on the fertilization and development of *Fucus serratus* L. (serrated wrack). Rapports et Proces-Verbaux des Reunions, Conseil International pour l'Exploration de la mer 171:184-185.

53. Jones, J.G. 1968. Methods of Studyiong the Effects and Metabolism of Hydrocarbons in Natural Environments. pp 145-150. In: Carthy, J.D. and D.R. Arthur (eds) 1968. **The Biological Effects of Oil Pollution on Littoral Communities.** Proc. of a Symposium held at the Orielton Field Centre, Pembroke Wales on 17-19 Feb 1968.

54. Kator, H. and R. Herwig. 1977. Microbial responses after two experimental oil spills in an eastern coastal plain estuarine ecosystem. pp 517-522. In **Proc. 1977 Oil Spill Conf.** American Petroleum Institute, Washington, D.C.

55. Krebs, Charles T. and Christopher E. Tanner. 1981. Cost Analysis of Marsh Restoration Through Sediment Stripping and *Spartina* Propagation. pp 386-390. In **Proc. 1981 Oil Spill Conf.** American Petroleum Institute, Washington, D.C.

56. Krebs, Charles T. and Christopher E. Tanner. 1981. Restoration of Oiled Marshes Through Sediment Stripping and *Spartina* Propagation. pp 386-390. **Proc. 1981 Oil Spill Conf.** American Petroleum Institute, Washington, D.C.

57. Linden, O., R. Elmgren and P. Boehm. 1979. The Tsesis oil spill: Its impact on the coastal ecosystem of the Baltic Sea. **Ambio 8**:244-253.

58. McCauley, Cyntha A. and Richard C. Harrel. 1981. Effects of Oil Spill Cleanup Techniques on a Salt Marsh. pp. 401-407. **Proc. 1981 Oil Spill Conf.** American Petroleum Institute, Washington, D.C.

59. Mackin, J.G. 1950. A comparison of the effects of application of crude petroleum on saltgrass, Distichlis spicata (L.) Greene. Texas A. & M. Res. Found.

60. Mitchell, C.T., E.K. Anderson, L.G. Jones and W.J. North. 1970. What oil does to ecology. **J. Wat. Pollut. Control Fed.**, 42: 812-818

61. Mitchell, N, B. Pyburn, W. J. Syratt, and P.D. Holmes. 1985. An Estuarine Oil Spill Incident in the United Kingdom. **Proc. 1985 Oil Spill Conf.** American Petroleum Institute, Washington, D.C.

62. Moody, A. I. 1989. Monitoring of Marsh Vegetation Response to a Jet-Fuel Spill at Vancouver International Airport. Unpublished report Prepared by AIM Ecological Consultants for Environment Canada, Conservation and Protection, West Vancouver, B.C.

63. Morris, I. 1967. **An Introduction to the Algae**. Hutchinson & Co. Toronto.

64. Nelson-Smith, A. 1968a. A Classified Bibliography of Oil Pollution. pp165-196. In: Carthy, J.D. and D.R. Arthur (eds) 1968. **The Biological Effects of Oil Pollution on Littoral Communities.** Proc. of a Symposium held at the Orielton Field Centre, Pembroke Wales on 17-19 Feb. 1968.

65. Nelson-Smith, A. 1968b. Biological Consequences of Oil Pollution and Shore Cleansing. pp73-80. In: Carthy, J.D. and D.R. Arthur (eds) 1968. **The Biological Effects of Oil Pollution on Littoral Communities.** Proc. of a Symposium held at the Orielton Field Centre, Pembroke Wales on 17-19 Feb 1968.

66. Nelson-Smith, A. 1973. **Oil Pollution and Marine Ecology**. Plenum, New York.

67. North, W.J. 1967. *Tampico* -a study of destruction and restoration. **Sea Frontiers, 13:212-217.**

68. North, W.J., M. Neuschul Jr., and K.A. Clandenning. 1965. Successive biological changes observed in a marine cove exposed to a large spillage of mineral oil. Pollutions Marines par les Microorganismes et les Produits Petroliers (April 1964):335-354.

69. Notini, M. 1978 Long-term effects of an oil spill on *Fucus* macrofauna in a small Baltic Bay. J. Fish. Res. Board Can. 35:745-753.

70. O'Brien, P.Y. and P.S Dixon. 1976. The Effects of Oils and Oil Components on Algae: A Review. **Br. Phycol. J. 11**:115-142.

71. Page, D.S, J.C. Foster, J.R. Hotham, E. Pendergast, S. Hebert, L. Gonzales, E.S. Gilfillan, S.A. Hanson, R.P. Gerber and D. Vallas, 1983. Long-term fate of dispersed and undispersed crude oil in two nearshore test spills. pp465-475. **Proc. 1983 Oil Spill Conf.** American Petroleum Institute, Washington, D.C.

72. Payne, Jerry F. and Robert Maloney. 1979. Are Petroleum Hydrocarbons an Important Source of Mutagens in the Marine Environment? pp. 533-535. **Proc. 1979 Oil Spill Conf.** American Petroleum Institute, Washington, D.C.

73. Pimentell, Emily M. & Roy F. Weston. 1985. Oil Spill Cleanup and Habitat Restoration--Little Panoche Creek, California. pp.331-334. **Proc. 1985 Oil Spill Conf.** American Petroleum Institute, Washington, D.C.

74. Ranwell, D.S. 1968. Extent of Damage to Coasal Habitats Due to the *Torrey Canyon* Incident. pp39-47. In: Carthy, J.D. and D.R. Arthur (eds) 1968. **The Biological Effects of Oil Pollution on Littoral Communities.** Proc. of a Symposium held at the Orielton Field Centre, Pembroke Wales on 17-19 Feb 1968.

75. South, G.R. and A. Whittick. 1987. **Introduction to Phycology.** Blackwell Sci. Pub. Oxford. pp. 266-267.

76. Stebbins, R.E. 1968. *Torrey Canyon* oil pollution on salt marshes and a shingle beach in Brittany 16 months after, Furzebrook Research Station, UK. Published by Nature Conservancy, London.

77. Stebbins, R.E 1970. Recovery of salt marsh in Brittany sixteen months after heavy pollution by oil. **Environ. Pollut.**1:163-167.

78. Steele, R.L. 1977. Effects of certain petroleum products on reproduction and growth of zygotes and juvenile stages of the alga *Fucus edentatus* De La Pyl (Phaeophyceae: Fucales). In Wolfe, D.A., (ed.) 1977. **Fate and Effects of Petroleum Hydrocarbons in Marine organisms and Ecosystems.** Oxford: Pergamon Press. 138-142.

79. Straughan, D. 1971. The influence of oil and detergents on recolonization in the upper intertidal zone. In *Proceedings of Joint Conference on Prevention and Control of Oil Spills*. API, EPA and USCG pp437-440.

80. Straughan, D. 1972. Biological Effects of oil pollution in the Santa Barbara Channel, In *Marine Pollution and Sea Life*, M. Ruivo (ed) 1972. Rome: Fishing News Books pp 355-359.

81. Teal, J.M., and Howarth, R.W. 1984. Oil spill studies: A review of ecological effects. **Environmental Management** 8:27-44.

82. Thelin, I. 1981. Effects in culture of two crude oils and one oil dispersant on zygotes and germlings of *Fucus serratus* Linnaeus (Fucales, Phaeophyceae) **Botanica Marina 24**:515-519.

83. Thomas, M.L.H. 1977. Long-term biological effects of Bunker C oil in the intertidal zone. In: Wolfe, D.A. (ed.) 1977. **Fate and Effects of Petroleum Hyudrocarbons in Marine Ecosystems and Organisms.** New York: Pergamon Press. pp. 238-246.

84. Thompson, Alyce, D. and Kenneth Webb. 1984. The Effect of Chronic Oil Pollution on Salt-Marsh Nitrogen Fixation (Acetylene Reduction). **Estuaries 7(1)**:2-11.

85. Thorhaug, A, and J. Marcus. 1987. The effect of Three Dispersants on Three Subtropical/Tropical Seagrasses. pp 124-126. **Marine Pollution Bulletin Vol.18(3) 1987.**

86. Thorhaug, Anitra, and Jeffry Marcus. 1985. Effects of Dispersant and Oil on Subtropical and Tropical Seagrasses. pp 497-501. **Proc. 1985 Oil Spill Conf.** American Petroleum Institute, Washington, D.C.

87. Van Gelder-Ottway, S. 1975. The Comparative Toxicities of Crude Oils, Refined Oil Products and Oil Emulsions. pp 287-302. In: Baker, J.M. (ed.) 1975. **Marine Ecology and Oil Pollution.** John Wiley & Sons, Toronto.

88. Vandermeulen, J.H. 1981. Geomorphological Alteration of a Hevily Oiled Saltmarsh (Ile Grande, France) As a Result of Massive Cleanup. pp. 347-351 **Proc. 1981 Oil Spill Conf.** American Petroleum Institute, Washington, D.C.

89. Walker, J.D. and R.R. Colwell. 1976. Measuring the potential activity of hydrocarbon-degradomg bacteria. Appl. Environ. Microbiol. 32:187-197.

90. Watton, Dan. 1985. A Coastal Marshland Rebuilding Technique with *Spartina alterniflora* after Singular Seasonal Oil Spills. pp.209-210 **Proc. 1985 Oil Spill Conf.** American Petroleum Institute, Washington, D.C.

91. Webb, J. W., G.T. Tanner, and B.H. Koerth. 1981. Oil Spill Effects on Smooth Cordgrass in Galveston Bay, Texas. **Contributions in Marine Science, Vol 24**, pp. 107-114, 1981.

92. Webb, James W. and Steve K. Alexander. 1985. Effects of Autumn Application of Oil on *Spartina alterniflora* in a Texas Salt Marsh. **Environmental Pollution (Series A) 38**:321-337.